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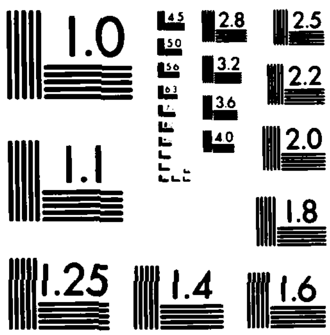

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PICOSECOND LIDAR TECHNIQUES IN

LABORATORY AND FIELD DIAGNOSTICS

AFOSR 83 - 0016

Final Scientific Report

prepared for:

AFOSR, Bolling AFB

Attn: Dr. L. H. Caveny

November 1, 1982 - January 15, 1984

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This one year project analyzed (but did not prove experimentally) the use of picosecond pulses in a lidar mode on laboratory flames. The advantage of very short pulses is predicated by two aspects. One is the elimination of background noise, since the picosecond time-gating of the detector will collect the whole signal of interest but only a tiny fraction

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) of the time-spread noise background (e.g., soot, walls,...). The other is related to the very short length of these pulses (∿ cm): it is the possibility to use the lidar/radar principle to convert the time history of the measured back scattered signals into a centimeter-resolved space distribution along the beam. In this fashion, Raman and other techniques can yield a detailed map of concentrations and temperatures in three-dimensional space, even in sooty combustors background, with the need of only one single porthole.

RESEARCH OBJECTIVES

The availability of picosecond laser systems opens a new potential in the field of diagnostics. It is now possible to observe chemical events over time intervals as short as 10^{-8} sec (e.g., fluorescence, bond-selective chemistry,...) without overlap with the much shorter 10^{-12} sec triggering signal. In addition, two specific effects are of special interest to real industrial flame diagnostics. One is the elimination of background noise, since the picosecond time-gating of the detector will collect the whole signal of interest but only a tiny fraction of the time-spread noise background (e.g., soot, walls,...). The other is related to the very short length of these pulses ($\sim$ mm): it is the possibility to use the lidar/radar principle to convert the time history of the measured back scattered signals into a millimeter-resolved space distribution along the beam. In this fashion, Raman and other techniques can yield a detailed map of concentrations and temperatures in three-dimensional space, even in sooty combustors background, with the need of only one single porthole.

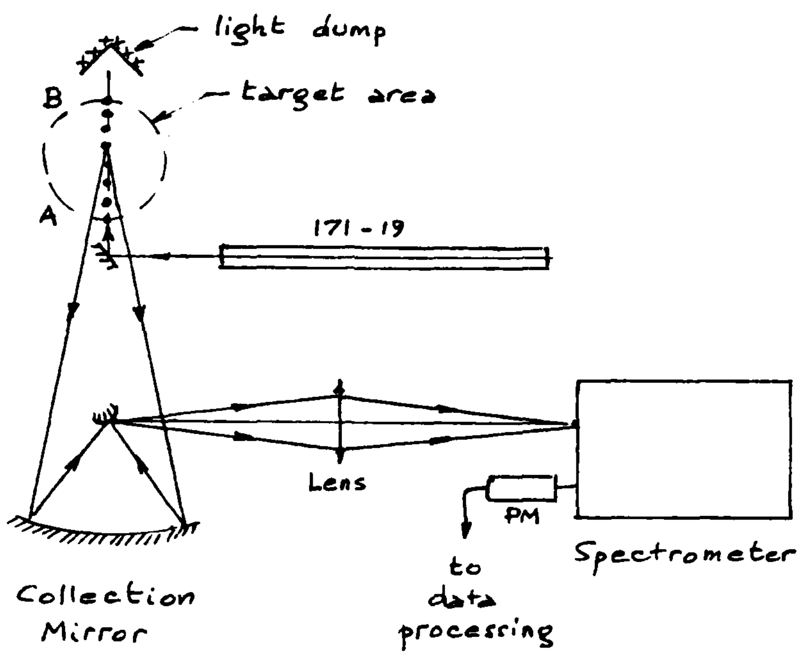
SUMMARY OF RESULTS

Over the 14½ months of the grant, several efforts were made to demonstrate the feasibility of laboratory or field measurements, using the "picolidar" concept.

A. Experiment at Berkeley

In the laboratory, the existence of another research program using picosecond techniques led to a cooperation between George Washington University and the University of California - Berkeley. One of Professor Daily's student (R. Gotlik) designed an apparatus illustrated on Figure 1. The purpose of this experiment was to feed the Raman signals back scattered from the segment AB into the optical system. The time-gating of these signals (30 cm $\sim$ one nanosecond) would give a concentration profile along the segment AB.

Unfortunately, one was unable to collect any signal, much less a time-gated distribution of signals, even when taking the larger Rayleigh signals at the laser frequency (5145Å). The analysis of the situation led to the following tentative explanation:



1) The mode locked laser (Spectra Physics Model #171-19 borrowed from the University "laser library") provided 80 million signals per second. Thus one obtained very weak pulses and even weaker scattered signals from each pulse.

Meanwhile, some Rayleigh reflections from other parts of the system were generating a considerable amount of background noise.

2) In addition, the maximum repetition rate of the amplifier discriminator (Pacific Precision Photometrics AD-6) was of the order of 50 MHz, which was less than the mode locker rate (80 MHz). Even if the discriminator had matched the laser repetition rate, it would have been far short of the time resolution corresponding to a 2 cm spatial resolution: 100 picoseconds!

Shortly after these results, this experiment was set aside, mainly because the equipment available from the laser library was not adequate for the task.

B. Streak Cameras vs. Digitizing Units

Following this experimental impasse, a review of the field of high speed detection was initiated. It led in particular to a discussion of two systems:

1) one by J. Ashire (NASA-Godard), who obtains ground atmospheric pressure from a satellite, by measuring the difference between the travel time of two beams at different frequencies (a form of interferometry). To differentiate between two very close measurements (typically a 5 nanosecond differential), he used a time interval unit (Hewlett Packard 8370, maximum resolution 20 psec) and a Tektronix R7912 digitizer, band width limited 500 psec.

Abshire suggested that our needs were more stringent since we wanted a <u>profile</u> with 20 psec resolution, not a single "stop", as it is provided by the HP 8370 unit. Such units (8 to 15 "stops") are available from Dr. Lescovar at Berkeley. On the other hand, the bandwidth limit of 500 p sec is a serious limitation if a profile is expected. Also another laser, with fewer but more powerful pulses is necessary for backscattering work: Yag lasers can yield several millijoules with repetition rates from 5 to 100 Hz.

In spite of this theoretical possibility, to be obtained at great expense, Abshire has preferred to convert his data collecting system to a Hamamatsu streak Camera with 2 psec resolution, interfaced with a computer and a TV monitor. In contrast with earlier predictions, these streak camera systems (said Abshire) can be mastered in a matter of a few hours. They give little trouble in operation.

2) A similar experience of ease of handling was obtained from Richard Elliott (Oregon Graduate Center), who uses a cheaper Hamatsu C 979 streak camera, çapable of 10 psec resolution. In his case, the difference of travel time due to multiple scattering in simulated clouds, verified Monte Carlo theories. This new technique could be applied to other media, including absorption.

The conclusion of these analysis is that the proposed picolidar research is feasible with the use of current streak camera systems.

C. Theoretical Calculations on Background Noise

1) The anticipated problem of background noise was discussed extensively in the proposal. Of particular concern is the laser-induced luminosity, as it is not clear that more power in shorter pulses reduces this effect.

In a simplified heat transfer study, Flower showed that the black body re-radiation of particulates depended non-dimensionally on the ratio of the particle radius and the laser pulse length (SAND 79-8607). A Raman scattering experiment with a 20 nanosecond pulse laser showed indeed that while induced luminosity is not appreciable in the micron radius range and above, it is not the case for very young soot (radii $\leq 0.05\mu$). In this latter case, nanosecond pulses generate enough surface temperature increase to create a black body radiation which swamps Raman signals (SAND 81-8608). The experiment was not continued.

However, the introduction of picosecond pulses (i.e. exposure times four orders of magnitude less than those used by Flower) could reduce dramatically (about two orders of magnitude) the surface temperature rise for a given particle radius (and thus the luminosity). Conversely, it would allow for the Raman probing of regions of the flame with much smaller soot particles, i.e. much closer to the flame front.

In order to prepare for such an experiment it was decided to improve on Flower's simplified analysis: several steps of theoretical heat transfer analysis were originated:

a) Unsteady heating of a homogeneous sphere by an isotropic radiation field.

b) Same problem with a parallel radiation field (laser beam).

c) Non homogeneous spheres and gas dynamic effects (soot).

d) Arbitrary surface behavior.

2) A basic problem emerged from this investigation: is it appropriate to use the Planck function as the equilibrium radiation of particles smaller than the dominant wave length ($\sim 1\mu$)? Such study has been contemplated by McGregor (JQSRT, 19, 659-664) and by Baltes (Infra Red Physics, 16, 1). The problem of radiation from very small particulates is relevant to soot radiation, especially in aromatic fuels.

LIST OF PUBLICATIONS

No publication was released, since the work did not progress far enough during that 14½ month period.

LIST OF PERSONNEL

Robert Goulard, Professor	4.3 man-months
Research Assistants	8 man-months

SPECIFIC APPLICATIONS OF THE RESEARCH

Beyond the proposed flame diagnostics, in the laboratory and in the field, an important application would involve the back scattering, not from gases, but from surfaces (ships, airplanes, missiles, vehicles), in several different ways:

a) the identification of a target by its three dimensional shape would be an improvement to the two dimensional sun or radar-reflection image in current targetting systems. Such an identification would also supply the location of the weakest points of the target. Moreover, it would introduce an identification process with a potential to be handled by a computerized pattern-recognition, without the need for a time consuming human interpretation, including transmission time.

b) groups of tightly spaced targets (airplanes, missiles, vehicles, etc...) could be imaged separately and disposed of in a manner consistent with their relative importance (e.g., trucks vs. tanks or troups, etc...).

c) picosecond laser pulses have a much sharper rise time than conventional backscattering probes. Thus the required signal-to-noise-ratio is obtained within a few picoseconds, a highly desirable feature if some fusing effect is desired at a precise and short distance of the target.

d) the additional availability of gaseous scattering might be of further use in identification in specific localized targets.

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